1

Introduction

Since the end of the Cold War, funding for the acquisition of new military aircraft has become scarce, and budgets for modernizing the existing, so-called "legacy" fleet have remained flat. As a result, the operational lifetimes of legacy aircraft are being extended well beyond their original design lifetimes. The average age of U.S. military aircraft is 20 years and increasing as a result of the low replacement rate. Figure 1-1 shows the almost year-by-year increase in the age of aircraft since 1997. Although extending the lifetime of the airframe is relatively straightforward, avionics systems, which are often based on technology from the 1970s and 1980s, are rapidly becoming obsolete. Even if these systems could be adequately maintained, they are generally not adequate for dealing with current and evolving missions, threats, and information-intensive battlefield environments.

As legacy aircraft age, the avionics systems are becoming more and more difficult to support and maintain. Many critical components are no longer in production or have become obsolete, and many former suppliers of military-grade components have either gone out of business or have stopped producing for the military market. Thus, more and more aircraft are being grounded while maintenance and support solutions are pursued. The Air Force reports that the mission-capable rate (i.e., the percentage of aircraft able to perform their primary missions, at any given time) of its aircraft declined from 83 percent to 73 percent during the 1990s, and indications are that this trend will continue in the near future (CBO, 2000). The Air Force attributes this decline in readiness largely to the aging of the aircraft fleet, particularly the aging of avionics[1] systems upon which the aircraft depend (personal communication with General John Jumper, Commander, Air Combat Command, August 4, 2000). The term "aging," usually used to refer to the degeneration and failure of components over time, is used in this report to refer to technical obsolescence in addition to physical degeneration.

Not long ago, the military provided a large and profitable market for the electronics industry. Since 1995 the military market has constituted less than 1 percent of the commercial integrated circuit market (Figure 1-2). As a result, the military must rely increasingly on commercial off-the-shelf (COTS) technologies[2] for both avionics system upgrades and new designs. Although COTS items are generally less expensive than comparable items designed to military specifications, the

[1] As defined in this report, the term "avionics" includes: internal electronic hardware, as well as external pods, such as electronic countermeasures; software required for navigation, communication, and other functions; external automatic test system hardware and software; ground electronics, communications, and air traffic control hardware.

[2] The term COTS is used here to mean any developed commercial technology available for sale; it need not be mass produced.

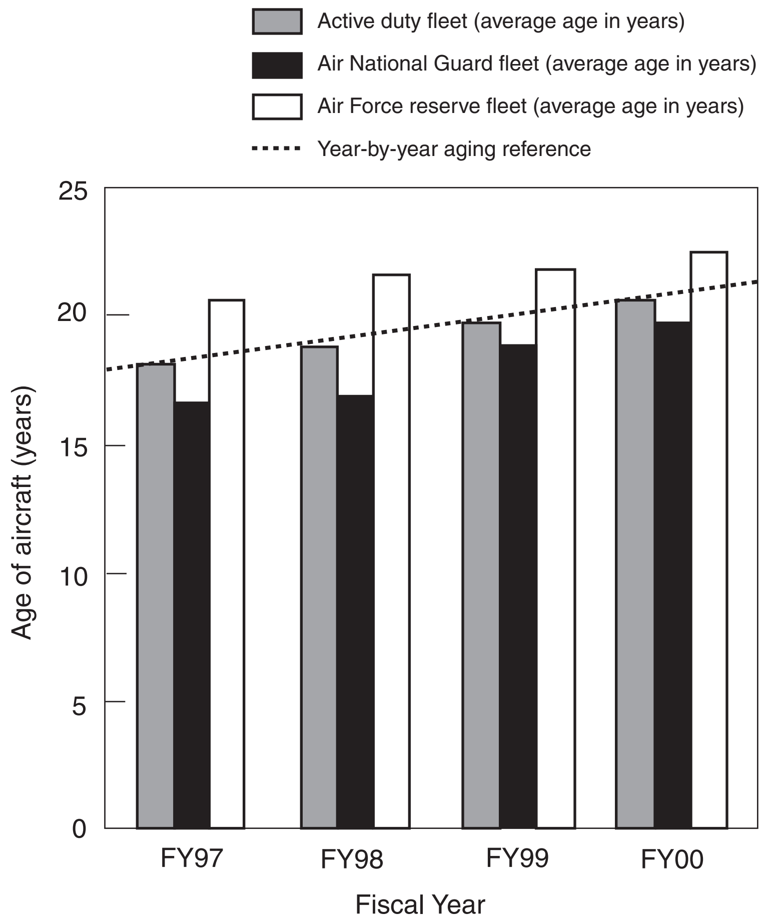

FIGURE 1-1 Average age of U.S. Air Force aircraft. Source: U.S. Air Force, 2000a.

technology-refresh cycle for COTS is typically 18 months or less, which exacerbates the ongoing problem of obsolescence for aircraft with lifetimes measured in decades.

Long weapon-system development and procurement cycles are also part of the problem. The F-22 Raptor program, for example, was begun nearly 20 years ago and is still at least five years away from fielding aircraft in squadron strength. Currently, $50 million a year is being budgeted to replace the "old" F-22 avionics with new hardware and software (Raggio, 2000). By the time the first production F-22 rolls off the line, its avionics systems will have undergone four refresh cycles.

According to Lt. General Robert Raggio, Commander of the Aeronautical Systems Center, the Air Force needs an additional $250 million to $275 million per year to address the problem of aging avionics in both legacy and new aircraft, not including the costs of training maintenance workers, suppliers, and operators (personal communication with Lt. Gen. Robert Raggio, Commander, Aeronautical Systems Center, October 6, 2000).[3] Each technology-refresh cycle entails added costs for regression testing, flight testing, training for pilots and support personnel, and configuration and spares management.[4]

In the 1980s, the Joint Integrated Avionics Working Group (JIAWG) was formed to establish a set of avionics characteristics for all of the services and for multiple platforms. Three aircraft were selected for initial application of the JIAWG principle: the Air Force advanced technology fighter (now the F-22); the Navy A-12 fighter; and the Army Comanche helicopter. The JIAWG also developed hardware standards, including

[3] Training costs for design and test engineers, logisticians, maintenance personnel, and aircrews, etc., are not currently included in cost models for aging avionics.

[4] No institutionalized processes, tools, or requirements have been developed for configuration management.

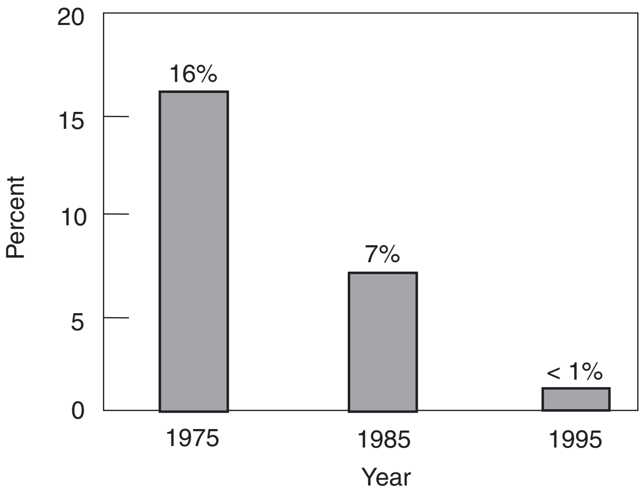

FIGURE 1-2 Decline in the military market share for integrated circuits. Source: Courtesy of Aerospace Corporation.

contractor-unique interfaces and bus structures, and the U.S. Department of Defense (DoD) mandated that Ada (a computer language) be used for software. In the committee's opinion, JIAWG's goals (i.e., reducing development, production, and support costs through the use of common items for all services) were laudable. In retrospect, however, the effort was fundamentally flawed because JIAWG's basic strategy was to define common modules, on the assumption that architecture would naturally flow from the module catalog. However, this approach is contrary to good system engineering (personal communication with Dr. J.M. Borky, Chief Scientist, Tamarac Technologies, February 16, 2001). In addition, the JIAWG did not anticipate the explosion in commercial electronics or the enormous market driving it. As a consequence, the system recommended by JIAWG proved to be unaffordable because it was predicated on government-supported research and development (R&D) and government markets to sustain the product lines.

Since the 1980s, the Air Force and the other military services have commissioned numerous task forces and committees and have funded programs to address various aspects of the aging/obsolescent avionics problem. Many of these have been successful in a relatively narrow or channeled area. However, these endeavors were not coordinated, were sometimes redundant, and, in general, did not use resources (human and monetary) synergistically, or develop and apply best practices.

In addition, the Office of the Secretary of Defense (OSD) and the Air Force have endorsed a modular, open-system approach (MOSA)[5] to ensure that new avionics systems will be more extendable and easily upgradable, as well as to reduce total ownership costs (TOC)[6] and improve readiness. All of the military services are beginning to recognize that MOSA could also result in significant benefits for upgrading and retrofitting to other types of systems. A major purpose of this study is to evaluate this approach.

STATEMENT OF TASK

This study was requested by the Assistant Secretary of the Air Force for Acquisition (SAF/AQ).[7] The study Committee on Aging Avionics in Military Aircraft, established by the National Research Council, was asked to perform the following tasks:

- Gather information from DoD, other government agencies, and industrial sources on the status of, and issues surrounding, the aging avionics problem. This should include briefings from and discussions with senior industry executives and military acquisition and support personnel. A part of this activity should include a review of Air Force Materiel Command's study on diminishing manufacturing sources to recommend ways to mitigate avionics obsolescence.
- Provide recommendations for new approaches and innovative techniques to improve management of aging avionics, with the goal of helping

[5] "Modular" systems involve the isolation of functional performance from the specific characteristics of the hardware and software used to implement the system. Ideally, an obsolete part could be removed and substituted with an upgrade without affecting the characteristics of the rest of the system. "Open" systems are generally modular but make use of nonproprietary interface definitions and standards available to multiple competitors. In theory, several prospective suppliers of an avionics module could compete for production and maintenance contracts, thus lowering the acquisition costs to the government.

[6] Total ownership costs are costs incurred over the entire life cycle of an avionics system, including research and development, manufacturing, and maintenance of the system throughout its service life.

[7] Because the Air Force requested the study, the majority of presentations made to the committee and much of the data gathered relate specifically to the Air Force. However, the committee notes that the problem of aging avionics is common to all of the services and that many of the solutions discussed will require a department-wide approach to be effective.

the Air Force to enhance supportability and replacement of aging and obsolescing avionics and minimize associated life cycle costs. Comment on the division of technology responsibility between DoD and industry.

FORMS OF OBSOLESCENCE

Military equipment "ages" in two basic ways: obsolescence in hardware or software that renders the equipment insupportable; and inadequate performance that renders the equipment unable to fulfill its mission. These problems are most severe in legacy aircraft but are also encountered in new systems, unless steps are taken to preclude or mitigate the problem.

Obsolescence of Hardware and Software

Aging Hardware

Legacy aircraft and electronics in general are both less reliable and more expensive to maintain than for new aircraft. The decrease in reliability is often attributable to the use of discrete, analog parts rather than integrated, digital components. In addition to the inherent differences in the reliability of parts, systems are also less reliable because of the lack of robustness in functional designs associated with cumbersome analog design processes. When older parts go out of production, (i.e., when the manufacturer no longer produces the units on a regular basis—or at all) numerous complications arise: an inventory of spare parts may not exist; the supplier is faced with the high cost of restarting the production line; and subtier manufacturers may have disappeared. In the worst cases, when no suitable components can be found, a redesign becomes necessary, which raises new problems: longer time to fill an order and the commitment of valuable engineering resources for a low-volume redesign (with attendant low profit margins). Thus, both the government and the manufacturer are in a losing situation (Hitt, 2000).

There are several ways of coping with diminishing manufacturing sources/out-of-production parts (DMS/OP). The three main ways are:

- purchase a lifetime supply, with attendant inventory costs
- redesign circuits to accept different, available parts or emulate the functionality provided by an obsolete part using newer technology
- replace entire modules or subsystems with new technology

Each of these strategies may be appropriate depending on many factors, such as the remaining service life of the particular platform or system, cost trade-offs, available budgets, and so on. However, coping with DMS/OP is more difficult than it first appears. Legacy avionics systems were not designed for ease of change or ease of testing. Therefore, the costs and complexity of inserting even new, available components can be high.

The often lengthy regression and flight testing required to validate that changes have not adversely affected safety or overall system performance have an even greater impact. Because of the structure of legacy avionics architectures, which have historically involved numerous, often subtle interactions between disparate components of a system, the causes and effects of changes are difficult to understand and even more difficult to predict. Therefore, extensive testing of the resulting system must be done to verify that no unforeseen consequences are lurking in the background. This process can be very time consuming and expensive.

Commercial Off-the-Shelf Technology

The defense industry is increasingly using COTS hardware and software, which raises another set of problems. In general, the half-lives of commercial electronic products are much shorter than those of military platforms. Although backward compatibility is sometimes possible, commercial business strategies are often based on planned obsolescence, which virtually guarantees that a COTS product will undergo several changes during the lifetime of any piece of military equipment. Therefore, a strategy for dealing with the obsolescence of COTS products must be developed.

Aging Software

Software obsolescence is a growing problem, especially for legacy equipment. Although software itself does not wear out, it must often be modified to accommodate incremental improvements and changes required to implement periodic block upgrades. Avionics software is developed in a host-target paradigm. The software is written, translated, simulated, and verified on a general purpose workstation with a rich development environment. The resulting object code is then downloaded for further testing and validation to the embedded target computer. The rapid progress of computing technology has rendered many host workstations obsolete and forced industry to replace them with new machines (not many PCs nowadays run on 16 MHz processors or boot to DOS). While the hardware is being upgraded, tools developers update their products (by discarding them and not supporting earlier versions). The updated versions of development tools (e.g., compilers, debuggers, linkers, and simulators) are often not compatible with the existing target software, requiring significant development efforts to produce a working product even when the original source code is available. Such scenarios have forced the industry to introduce frequent target software changes, as well as system redevelopment.

Many legacy military platforms contain software written in a variety of obsolete or obsolescing languages, such as machine-assembly languages, JOVIAL, and, to a lesser extent, Ada.

The commercial market, for which the vast bulk of software is written, has evolved its own languages (e.g., C, C++, JAVA, etc.), and funding for most R&D on software and related support tools is now directed toward supporting these languages. Because most software courses taught by U.S. educational institutions are focused on the needs of the commercial world, the number of software engineers skilled in legacy, military-unique languages is shrinking. Thus, the obsolescence of military software is complicated by two problems: (1) the increasing cost of maintaining legacy software maintenance tools; and (2) the decreasing number of technical personnel experienced in legacy software. In addition, much of the documentation for legacy software is inadequate by today's standards and can only be interpreted by specialized personnel.

Inadequate Performance of Hardware/Software Systems

Another type of avionics systems obsolescence is inadequate performance of aging systems in terms of meeting internal or external requirements of the related weapons systems.

Internal Performance Requirements

Internal requirements encompass improvements in safety, reliability, and maintainability, which are usually mutually dependent. Systems upgrades that address all three internal requirements reduce maintenance costs and increase availability and readiness. Orders-of-magnitude improvement in reliability can only be achieved through advanced, solid-state electronics and disciplined design processes.

External Performance Requirements

System upgrades for external requirements include the ability to fulfill new missions, meet new threats, and operate in the evolving global air traffic control system. Sensor systems, such as radar, must cope with increasingly small target cross sections and growing surveillance requirements; avionics must be modified to be compatible with new precision weapon systems; and electronic warfare systems must be continually updated to meet new threats. Because most of these requirements increase demands on legacy computing/processing capabilities, new hardware, as well as significant changes in software, are required.

New warfighting priorities, which revolve around information superiority, also have a large impact on military electronic systems. Battlefield strategies increasingly call for a "system-of-systems" approach, in which assets on land, sea, and air must be interoperable and closely coordinated. This requires capabilities for high-speed data transmission and processing, including the ability to receive and process information from anywhere in the operational network. These capabilities will require significant upgrades to avionics systems on a continual basis.

The avionics content of new airframes, such as the Joint Strike Fighter (JSF), is approaching 40 percent of total system cost because of the greatly expanding modes and features now expected of modern fighter aircraft and the increasing use of multiplatform, offboard information (see Figure 1-3). Even though legacy aircraft cannot possibly match these capabilities, they must be upgraded as much as practical, especially if system interoperability is required.

Required Upgrades in a Free-Flight Environment

Many existing types of aircraft need mandatory avionics upgrades to operate in the air traffic environment. For example, avionics dictated by the Global Air Traffic Management (GATM) Program will have to be installed in most of the Air Mobility Command aircraft, many of which are already undergoing mandated

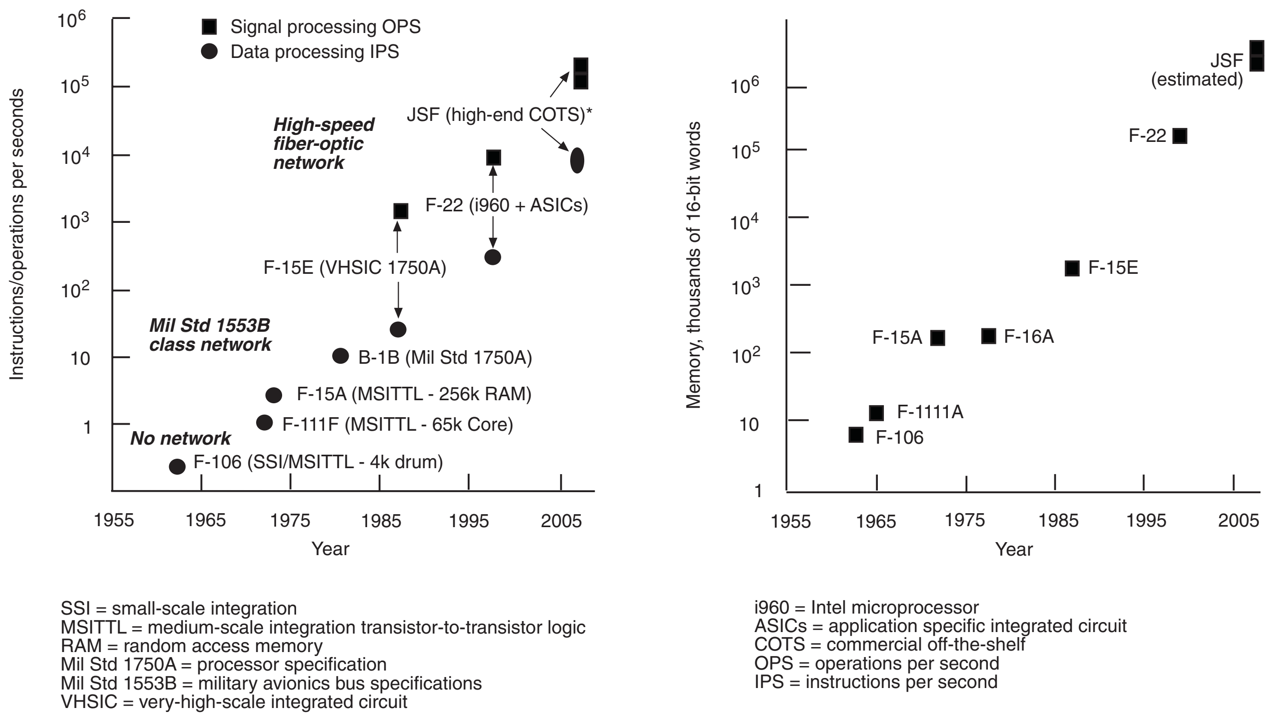

FIGURE 1-3 Historic trends in avionics processing.

modifications, including the installation of the traffic collision avoidance system (TCAS) and ground proximity warning equipment. Combat aircraft from Air Combat Command may be required to make similar modifications in the future. These modifications do not address problems presented by avionics systems/subsystems that drive high maintenance costs and high TOCs.

The modernization/upgrading of avionics systems and the support of older, out-of-production components are related. Indeed, mandatory modernization may provide opportunities to address the DMS/OP problems. The capability/performance upgrades necessary for aircraft platforms to operate for long service lives could be combined with other improvements, such as replacing older avionics components that have particularly high support costs, for relatively little additional cost.

FUTURE MANAGEMENT OF OBSOLESCENCE

In the future, the problem of aging avionics must be addressed in the design of current and new systems. The bottom-line goal of MOSA is to alleviate the DMS/OP maintenance problem and to accommodate modifications and upgrades economically, thus reducing TOCs and improving readiness. Mitigating the aging avionics problem will require more than new technical approaches, but no technology breakthroughs will be necessary. The challenges can be grouped into four categories:

- *Enterprise Management.* DoD and the Air Force are complex organizations with fragmented management responsibilities for weapon system platforms. Implementing common solutions across various vintages of a single platform, different platforms, and across the services is extremely difficult.
- *Budgetary Challenges.* Managers faced with flat or declining discretionary budgets often lack the resources and flexibility to replace avionics components and subsystems that have high operating costs with designs with lower TOCs.
- *Technical Challenges.* The goal of MOSA is to make avionics systems easier to change and

upgrade; however, the concept has not yet been fully defined, and its acceptance as a DoD-wide design and development strategy for avionics will require better supporting tools and retraining of personnel.

- *Business Challenges.* DoD and industry will have to develop new business models that support competition and investment in R&D by suppliers in a MOSA environment. Business incentives must be defined and included in the avionics acquisition process.

REPORT STRUCTURE

Chapter 2 is a broad overview of the magnitude of the problem of aging avionics. Chapter 3 provides an overview of ongoing government and industry initiatives to address the problem of aging avionics. In Chapter 4, the committee presents its observations and assessments based on analyses of presentations, briefings, and data from other sources. Chapter 5 provides a summary of the committee's findings and recommendations.